Developing of a Prototype Land Information Sensor Web (LISW)

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Abstract- **Sensor webs can eclipse the value of disparate sensor components by reducing response time and increasing scientific value, especially when integrated with science analysis, data assimilation, prediction modeling and decision support tools. The prototype Land Information Sensor Web (LISW) is a project sponsored by NASA, trying to integrate the Land Information System (LIS) in a sensor web framework which allows for optimal 2-way information flow that enhances land surface modeling using sensor web observations, and in turn allows sensor web reconfiguration to minimize overall system uncertainty. This prototype is based on a simulated interactive sensor web, which is then used to exercise and optimize the sensor web - modeling interfaces. These synthetic experiments provide a controlled environment in which to examine the end-to-end performance of the prototype, the impact of various design sensor web design trade-offs and the eventual value of sensor webs for particular prediction or decision support. In this paper, the progress of the LISW study will be presented, especially in scenario experiment design, sensor web framework and uncertainties in current land surface modeling.**

In this paper, the latest advances of design and implementation of a framework to integrate land surface modeling and a sensor web, a sensor web simulator (SWS) and as well as some data assimilation experiments based on the virtual sensor observations will be reported. The study of a virtual Land Information Sensor Web (LISW) is expected to provide some necessary priori knowledge for designing and deploying the next generation Global Earth Observing System of Systems (GEOSS) and to benefit a wide community of scientists from land surface modeling and engineers from space and sensor technology.

Keywords- **Land Surface Modeling, Sensor Web, Data Assimilation, Remote Sensing**

I. INTRODUCTION

Advances in understanding of soil-water dynamics, plant physiology, micrometeorology and the hydrology that control biosphere-atmosphere interactions have spurred the development of Land Surface Models (LSMs), whose aim is to represent simply, yet realistically, the transfer of mass, energy and momentum between a vegetated surface and the atmosphere (Sellers et al., 1986). LSMs that our team uses regularly include NCAR's Community Land Model (CLM) (Dai et al, 2003) and NCEP's Noah LSM (Chen et al. 1996). LSM predictions are regular in time and space, but these predictions are influenced by errors in model structure, input variables, parameters and inadequate treatment of sub-grid scale spatial variability. Consequently, LSM predictions are significantly improved through observation constraints made in a data assimilation framework. Charney et al. (1969) first suggested combining current and past data in an explicit dynamical model, using the model's prognostic equations to provide time continuity and dynamic coupling between the fields. This concept has evolved into a family of techniques known as data assimilation. In essence, hydrologic data assimilation aims to utilize both our hydrologic process knowledge, as embodied in a hydrologic model, and information that can be gained from observations. Both model predictions and observations are imperfect and we wish to use both synergistically to obtain a more accurate result. Moreover, both contain different kinds of information, that when used together, provide an accuracy level that cannot be obtained individually. Data assimilation techniques were pioneered by meteorologists (Daley, 1991) and have been used very successfully to improve operational weather forecasts for decades. However, hydrologic data assimilation has a much shorter history and has enjoyed significant advancement over the past decade by building on knowledge derived from the meteorology and oceanography data assimilation experiences.

Several multi-sensor satellites are currently operating which provide multiple global observations of the land surface, and its related near-atmospheric properties. However, these observations are not optimal for addressing current and future land surface environmental problems. The next generation constellations of smart satellites, which NASA is developing, can therefore be categorized as sensor web since the satellites are likely to be reconfigurable and may be able to communicate with each other based on the changing needs of science and available technology. These space-borne sensor webs, in combination with similar airborne and ground based sensor webs, will provide an unprecedented opportunity to allow for optimal 2-way information flow that enhances environmental modeling using sensor web observations, and in turn, will allow sensor web reconfiguration to minimize overall system uncertainty.

A sensor web is more than a collection of satellite sensors. According to a most recent definition by NASA/AIST 2007 Sensor Web investigator meeting, “A Sensor Web is a coherent set of heterogeneous, loosely-coupled, distributed nodes, interconnected by a communications fabric that can collectively behave as a single dynamically adaptive and reconfigurable observing system”. That means, a sensor web is a system composed of multiple platforms interconnected by a communication network for the purpose of performing specific observations and processing data required to support specific science goals. It is a networked set of instruments and analysis platforms sharing information so that sensor behavior can be modified based on that shared information and the specific observation objectives. An individual sensor node in this web is a device capable of measuring, either directly or indirectly, some physical phenomenon. And an instrument is a device containing a sensor and the necessary components for controlling the sensor and capturing the measurements. These sensors and instruments may be housed in in-situ platforms like weather stations or buoys or mounted onto airborne UAVs, balloon or airplanes, space-borne platforms like the EO-1 platform. Each type of platform has its merits in terms of cost, time/space resolution, aerial coverage, ease of deployment, coverage, etc.

In this paper, the latest advances of design and implementation of a framework to integrate land surface modeling and a spaceborne sensor web, a sensor web simulator (SWS) and as well as some data assimilation experiments based on the virtual sensor observations will be reported. The study of a virtual Land Information Sensor Web (LISW) is expected to provide some necessary priori knowledge for designing and deploying the next generation Global Earth Observing System of Systems (GEOSS) and to benefit a wide community of scientists from land surface modeling and engineers from space and sensor technology.

II. Methodology

The prototype Land Information Sensor Web (LISW) is a project sponsored by NASA Advanced Information System Technologies (AIST) Program. In this study, the Land Information System (LIS) will be integrated with a sensor web framework, which allows for optimal 2-way information flow that enhances land surface modeling using sensor web observations, and in turn allows sensor web reconfiguration to minimize overall system uncertainty. This prototype is based on a simulated interactive sensor web, which is then used to exercise and optimize the sensor web - modeling interfaces. These synthetic experiments provide a controlled environment in which to examine the end-to-end performance of the prototype, the impact of various design sensor web design trade-offs and the eventual value of sensor webs for particular prediction or decision support. Through an analysis of the virtual Land Information Sensor Web (LISW), it is expected to provide some necessary priori knowledge for designing and deploying the next generation Global Earth Observing System of Systems (GEOSS). The framework of LISW is shown in Figure 1.

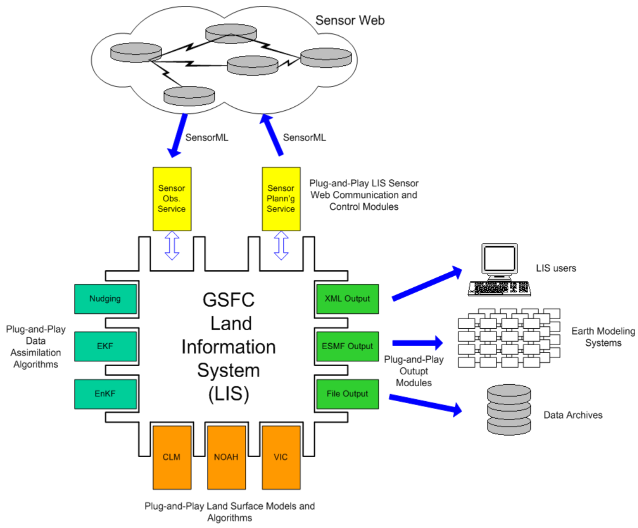

Figure 1: LISW Framework

LISW is based on the Land Information System (LIS) software framework. The recently developed, 2005 NASA Software of the Year award winning Land Information System (LIS; Peters-Lidard et al., 2004; Kumar et al., 2004) unifies and extends the capabilities of the ¼ degree GLDAS (described above) and the 1/8 degree North American LDAS (NLDAS; Mitchell et al., 2004) in a common software framework capable of ensemble land surface modeling on points, regions or the globe at spatial resolutions from 2x2.5 degrees down to 1km. The 1km capability of LIS allows it to take advantage of the latest EOS-era observations, such as MODIS leaf area index and surface temperature, at their full resolution. The hallmark of LIS is its object-oriented software engineering design and integrated high performance computing and communications technologies that enable

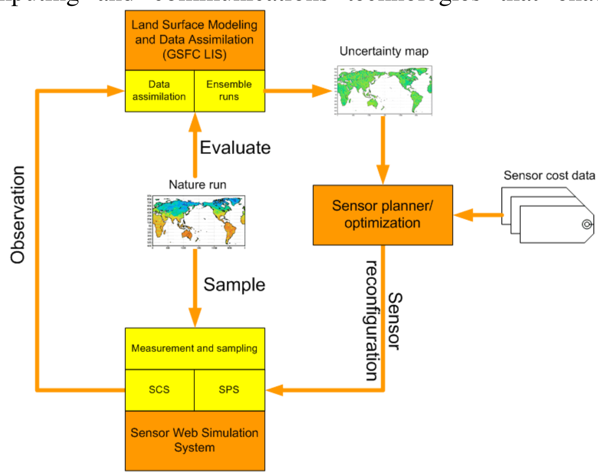

Figure 2 Flowchart of LISW

high-resolution ensemble land surface modeling. Examples of this design include the current LIS "plugins" for land surface models, meteorological inputs, parameters and grids/domains, which allow users to implement new functionality in any one area without affecting the rest of the code.

LISW further extends the capacity of LIS by enhancing the interactions between land surface modeling and sensor web. The flowchart of LISW is shown in Figure 2.

A. Scenario Development

The Land Information System (LIS5.0) is employed to generate three years' (from 2003 through 2005) global synthetic "land truth", on which the global land surface scenario and LISW experiments will be based. The spatial resolution of the global "land truth" is at ¼ degree and the temporal interval is 3 hours. The land surface model which was chosen to generate the land surface "true state" is CLM2.0. More details of the scenario development discussed by (Houser, Su, Tian, et al., 2007; Su, Houser, Tian, et al., 2007).

B. Sensor Web Simulation

The sensor web Simulation or Simulator is to generate the virtual sensor web observations which are then fed into the land information system.

The input data for the SWS will be based on the synthetic land truth generated in the scenario development. The layout of the input data shall be the standard LIS output format for binary data.

The output data of SWS will be sensor observations which can be saved on disk and can feed the Land Surface Models in LIS via Data Assimilation (DA). The figure below shows the relationship between LIS, SWS and the Sensor Web Framework. The Sensor Web Framework will be discussed in the following section.

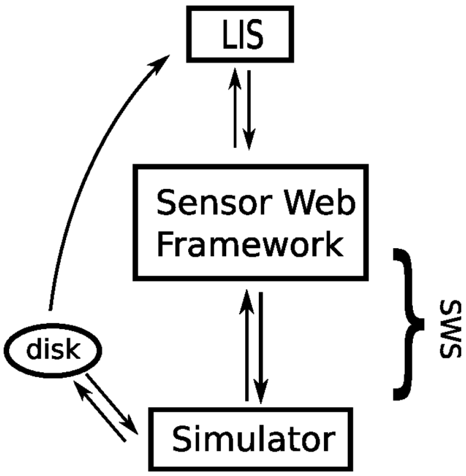

Figure 3: Illustration showing the high level design of SWS

The properties of a sensor web are described in SMS data structure, from the perspectives of different viewpoints, such as sensor budget, accuracy, lifetime, orbit, etc. The interfaces of SMS define the internal and external communication between sensors or between sensors and the Land Surface Models.

The architecture design of SMS deals with such issues as how to initialize the sensor, how to maintain the main control loop and how to finalize (shut down) the sensors.

C. Sensor Web Framework Design

There is an on-going project on Sensor Web Enablement (SWE) organized by the Open Geospatial Consortium (OGC), trying to implement SWE in Python (http://www.python.org) which is an open-source, object-oriented, programming language. Their approach to implementing the OGC SWE as a web service is based upon REST (REpresentational State Transfer), rather than SOAP. This python/REST combo is an interesting approach, and is quite a deviation from the popular java/SOAP implementation. SWE only provides a standard, and does not provide a working system for the community. We need to build our own. A suitable middleware is the key. We will conform to the de facto Sensor Web Enablement (SWE) standard proposed by the Open Geospatial Consortium (OGC). We plan to implement Sensor Web Enablement (SWE) via java/SOAP as a middleware, where some customization will be made for special use in LISW. The schematic figure (Figure 4) below shows how to integrate Sensor Web Framework with LIS.

The middleware in the Sensor Web Framework handles the messages between LIS and SWS. It provides a seamless communication tool to process both sensor web reconfiguration requests which is usually initiated by land surface models in LIS, and the feedback of the sensor web simulator, which generates the observation data trying to lower the uncertainties in land surface modeling.

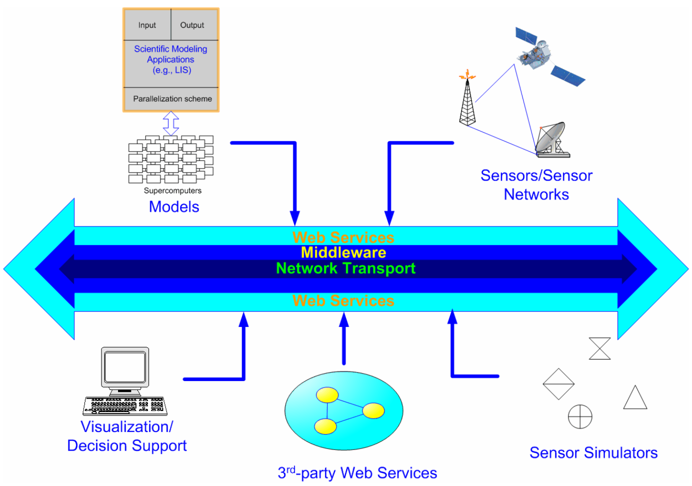

Figure 4: Sensor Web Framework

D. Data Assimilation Experiments

The virtual sensor observations are incorporated into the land information system via an approach of data assimilation which is an En-KF method and currently supported in LIS5.0. There are 4 different datasets generated from the data assimilation experiments:

- Control Run, "virtual land truth" from the CLM model output
- Virtual Observations, generated from the sensor web simulator
- Openloop Run, Noah model outputs without any observations
- Assimilated Run, Noah model outputs with the assimilation of the virtual observations

By assessing the improvement of model predictions from the assimilated run, we can have an estimate of how the different configuration of the sensor web can impact on the land surface modeling and then find out an optimized way to design and manage the virtual sensor web.

III. PRIMARY FINDINGS AND PRELIMINARY RESULTS

The study of Land Information Sensor Web has made progresses in the four different areas, which correspond to the methodology discussed in the previous section (Section II).

Three years of "global land truth" has been simulated based on CLM2 from LIS. The input data and output variables

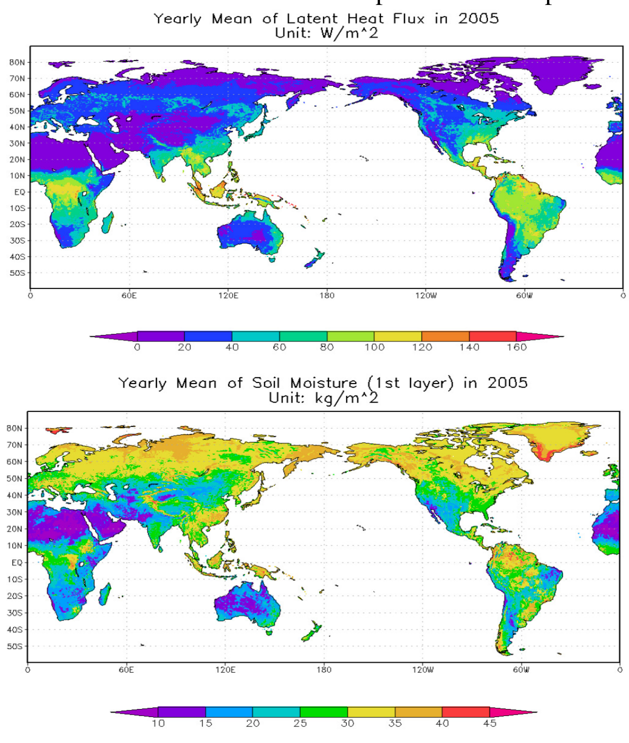

Figure 5: Example of Simulated "Global Land Truth" for 2005

were described in previous sections. Figure 5 shows an example of the simulated 1/4 degree "land truth" in 2005. The upper panel shows the annual mean of the latent heat flux and the lower panel is the annual mean of the first layer soil moisture.

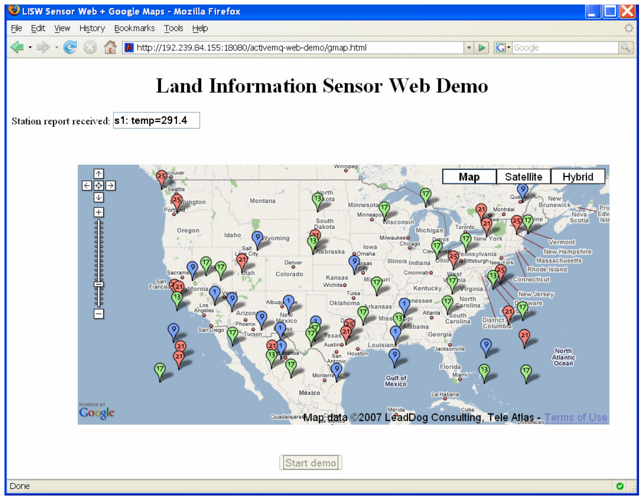

Figure 6 Demonstration of the Integration of Sensor Web Simulator and the Sensor Web Framework

The design and implementation of the sensor web simulator and the sensor web framework are completed. The figure above (Figure 6) shows a captured picture which is a simple demonstration of the two components in LISW. In this experiment, the scattered ground sites return the measurements of surface temperatures and the frequency of the measurements can be adjusted by sending out an event to a particular site. The values of the temperature measurement are then shown lively in a google map.

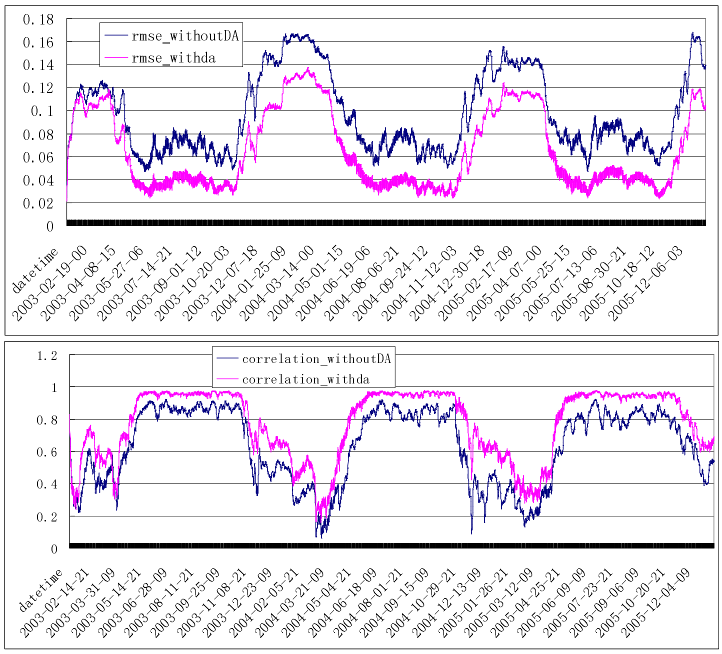

Figure 7 Data Assimilation Experument

Data assimilation experiment was done to study the 1st layer soil moisture for 3 consecutive years from 2003 through 2005. Figure 7 shows the comparison of RMSE (Root Mean Square Error) for open loop run and assimilated run (as defined in Section II *D*). Both of the RMSEs here are calculated based on the control run. It reveals that in all the situations, the assimilated run is in a better agreement with the control run than the open loop run, considering that it has a less RMSE and a higher correlation coefficient. An obvious seasonal variation of the RMSE and correlation coefficient is also found, which may be caused by the different model physics between the CLM and the Noah in winter and spring seasons when the deviation is larger.

IV. CONCLUSIONS

In this paper, the latest advances of design and implementation of the LISW components, which include a framework to integrate land surface modeling and a ensor web, a sensor web simulator (SWS) and as well as data assimilation experiments based on the virtual sensor observations, were presented. From the data assimilation experiments, it was revealed that the assimilation of sensor web observations is beneficial to achieve a better agreement with the control run. The seasonal variation of the data assimilation performance was identified. Further study to investigate this phenomenon by numerical simulation on a supercomputer will be our future plan.

ACKNOWLEDGMENT

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